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The Deep Sea Moorings Fishbite Problem\*

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ABSTRACT

Evidence gathered to date clearly shows that moorings set far away from continental shores are subjected to severe fishbites. These bites occur from the surface to depths well within the bathypelagic zone, 1000 meters or more. The dimension of the fishbite problem is first reviewed. A data base which spans over twenty years and encompasses hundreds of moorings deployed world wide is used to delineate the space and time dependence of fishbite attacks. This information is important when evaluating risks. Who are the culprits and why they do it is reviewed next. This knowledge is important when devising preventative methods. Granted that fishbite damage is a real possibility, how does one distinguish it from other plausible causes of rope failure? Observations, laboratory procedures, and rationales used to answer this question with a fair degree of assurance are described next. Finally the paper reviews the preventive and the curative methods which hopefully can protect mooring lines from the mechanical damage inflicted by fish teeth.

Often parted ends show effects of both cutting and tensile break, e.g. truncated ends on the cut yarns and a "ponytail" appearance on yarns broken by tension, as shown in Figure 2.



Figure 2. 1 1/2" Nylon rope damaged by fishbite (23).

INTRODUCTION

Two types of mooring lines are used in deep sea moorings. One is an unjacketed rope of synthetic fiber. When used for towing and mooring, this type has many favorable properties, but it is highly susceptible to cutting. A second type is a line made of synthetic fibers, or metal wires which has been covered with a plastic sheath for purposes of insulation, improved ease of handling, or prevention of corrosion. The latter kind of line may fail if its plastic sheath is punctured or stripped off. Both types of lines have been damaged in the marine environment.

Ropes of synthetic fiber have been found severed or cut part way with cuts appearing clean as though made with a keen edge (Figure 1).



Figure 1. Typical fishbite on 5/16" diameter polypropylene rope.

Figure 3 shows the effect of a biting attack upon plastic sheathing on a metal line. Steel wires within were exposed to the corrosive action of sea water.

Most information relative to fishbite has been developed from experience with deep sea mooring lines but there is evidence that other items such as thermistor chains, acoustical arrays, and sonar domes (11) have been attacked.

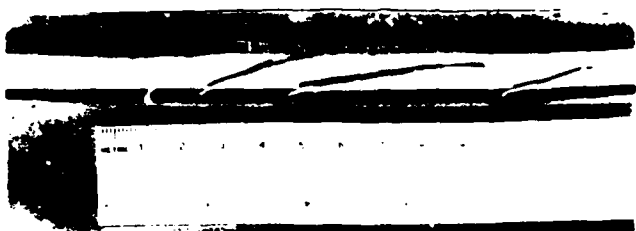


Figure 3. Fishbite on plastic jacket of steel wire rope (23).

In an attempt to obtain documented cases of fishbite as a cause of cuts found on deep sea lines, two experimental moorings were established off the shore of Bermuda (27 & 28) in 2000 meters of water depth. The first was set in the late spring of 1964. After a week in the water, the line was found to have more than 40 groups of cuts, most of them between 400 and 800 meters below the surface. Twenty-nine groups of cuts were in pairs, occurring on only one side of the line. The separation of cuts which were in pairs varied from 30 to 60 mm. If indeed, as later was found to be the case, they were the result of biting, then a direct measurement of one dimension of the biter, namely jaw width, was on record.

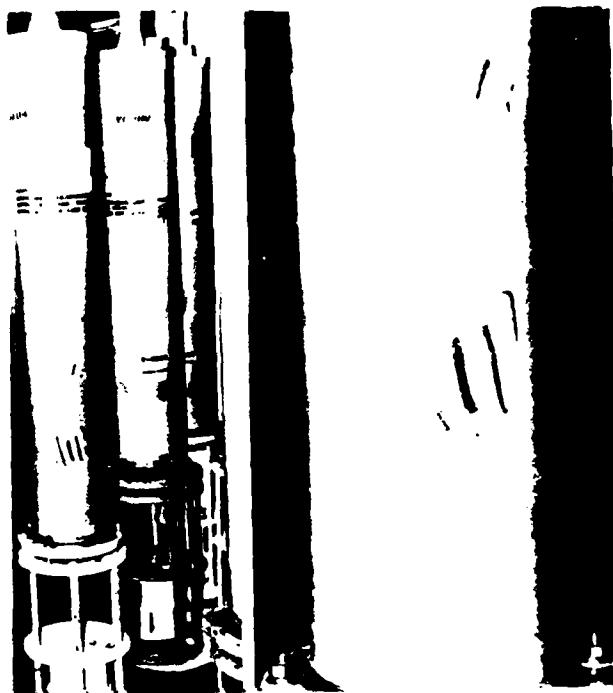
The second mooring was set in the fall of 1964. Wood and asbestos board panels were attached at various intervals to collect fouling and boring organisms. This array was exposed for approximately six weeks. The jacket of the second mooring had many cuts upon retrieval after 40 days in the water. As in the first case, many cuts were paired and only on one side of the line. Tooth points were recovered from both polyethylene line covers and pine panels. The suspicion that lines were being bitten became a fact.

Evidence also shows that fishbite attacks have caused damage to Savonius rotors and small plastic propellers used in current meters. On occasions (Figure 4) sharks will even attack an entire instrument case.

#### DIMENSION OF THE FISHBITE PROBLEM

##### A. The Woods Hole Oceanographic Institution (WHOI) experience.

Log sheets of 550 WHOI moored stations were reviewed and data relative to fishbite tabulated for the years since 1967. The fishbite data were recorded by observers with varied experience in detecting fishbite and often under pressure of other duties. The number of fishbites reported in the log sheets is therefore regarded as conservative.



VACM current meters      Close up of teeth marks

Figure 4. Shark attack on current meter set 20 meters below the surface (1986 - 27°N, 69°43'W).

431 or 78% of all moored stations in the study were deployed in the North Atlantic Ocean. In terms of world ocean space, therefore, the representation of data is predominately from the Atlantic Ocean, north of the Equator. What follows by way of interpretation of the data can be applied to that area with some degree of confidence. With reference to other parts of the world's oceans, conclusions can only be tentative until more uniform coverage has been obtained.

Of the total number of stations, 385 or 70% were located in what will hereinafter be designated as the "Fishbite Zone." It is an ocean space bounded by latitude and by depth. It lies between 40° north and 40° south latitude. The depth boundaries are between the water-air interface and 2000 meters below the surface.

In the time period covered in the present report, 36 WHOI buoys were deployed outside the area bounded by the 40° north and south parallels. Of these only 2 showed signs of fish attacks. This result supports the present use of 40° latitude as a boundary for the Fishbite Zone. With reference to depth, 116 moored arrays were placed inside the 40° parallels but with all components at depths greater than 2000 meters. Of these, none were reported bitten.

A summary of yearly fishbite incidence is shown in Figure 5. Over this period biting appears to have been a significant hazard as 28% of the mooring lines set in the Fishbite Zone were reported found with typical fishbite markings.

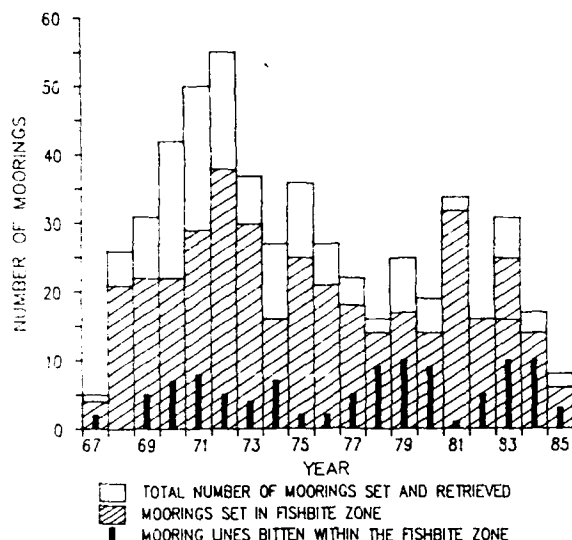


Figure 5. Yearly distribution of fishbites from WHOI mooring station logs (1967-1985).

One may well ask whether risk of fishbite was found to be uniform throughout the Fishbite Zone. The data indicated that the risk rose as stations were established closer to the equator, as shown graphically in Figure 6. Somewhere within 10 degrees of the equator about 2/3 of all mooring lines were bitten. As latitude increased, the percentage fell off until the risk of biting became very small beyond 40°N.

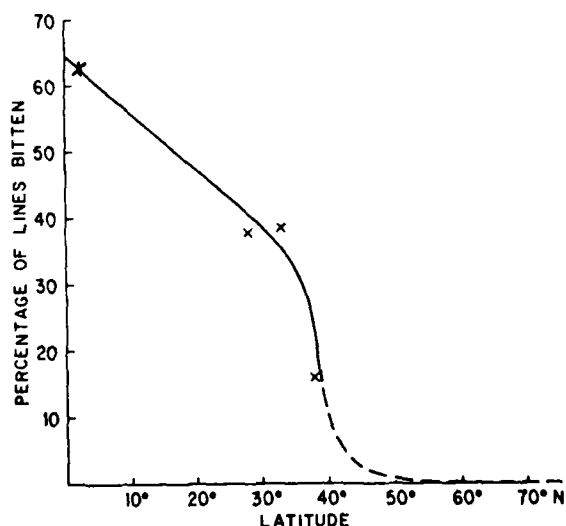


Figure 6. Percentage of lines bitten vs. latitude.

To date, fishbite has been regarded as mostly a deep water phenomenon. The present data base confirms such a viewpoint. No fishbites were recorded at 61 stations in 2000 meters of water or less, though all were within latitudes where fishbite had been encountered in deeper water. Until more evidence becomes available, however, one should probably not write off the possibility that fishbite may occur in shallow water.

One might surmise that the time a mooring line is in the water should have some correlation with the probability that it will be bitten. The record of bites vs. duration is shown graphically in Figure 7. Considerable variation is evident from one time interval to another. Overall, an upward trend in percentage of lines bitten seems indicated but fluctuations are so large that any closer analysis is difficult.

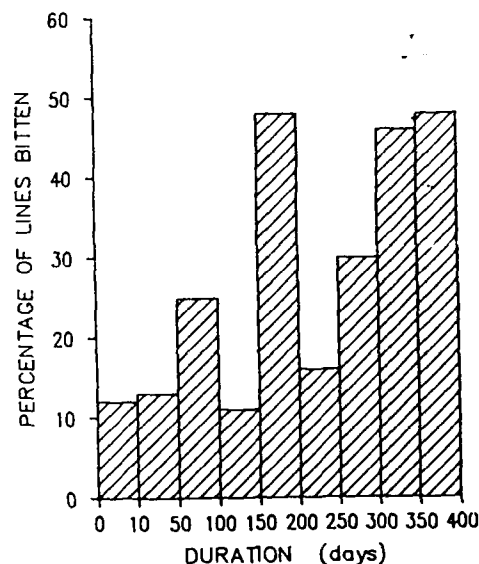


Figure 7. Percentage of lines bitten vs. duration.

Another approach to the problem is to treat the data in such a way that in effect, short duration times are regarded as part of longer duration times (Figure 8). In this approach not all possible environmental conditions are represented but the impact of conditions during any one time interval is lessened and, of course, as time intervals become larger and more moorings are deployed a limit is reached where all environmental factors are considered. Time then becomes the dominant variable.

Based on these data a biting rate of about 3% per 100 days is indicated. It is reasonable to expect that on an average, one mooring out of four would be attacked if set within the Fishbite Zone for a period of up to 450 days.

Detailed relations between fishbite and depth were obtained from the experimental mooring deployed off the coast of Bermuda as previously mentioned. The mooring line was a 1x19 galvanized steel wire rope coated with polyethylene to an outside diameter of

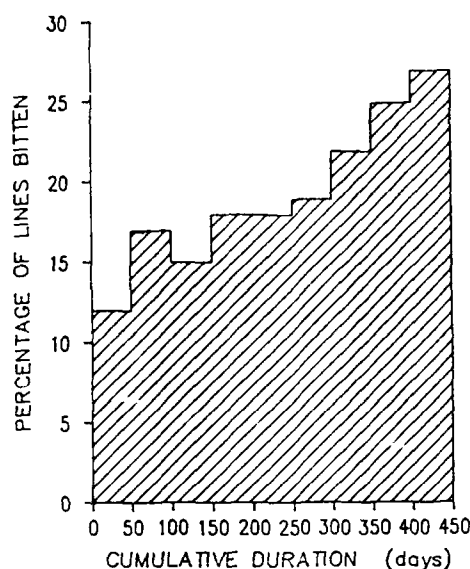


Figure 8. Percentage of lines bitten vs. cumulative duration.

8.13 mm. The coating took excellent dental impressions and retained a few fragments of teeth. The recovered line was run through a metering device and records were made of the depths at which evidence of biting was found. The frequency of bites as a function of depth thus obtained is plotted in Figure 9, together with the mean water temperature.

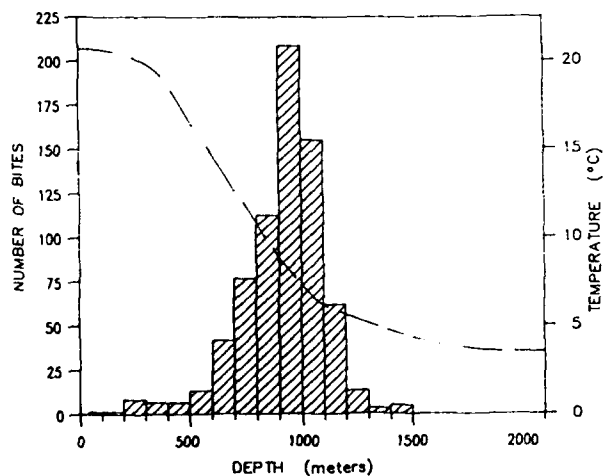


Figure 9. Frequency of bites vs. depth (Bermuda) (23).

As can be seen, the major fraction of the bites occurred between 600 and 1200 meters with the peak of activity between 900 and 1000 meters. This indicates that the population of biters was concentrated near the bottom of the permanent thermocline. A detailed study of two moorings set further north produced the bite histograms shown in Figure 10 (26).

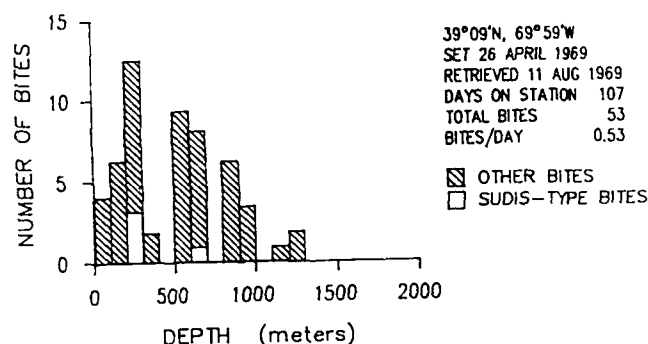
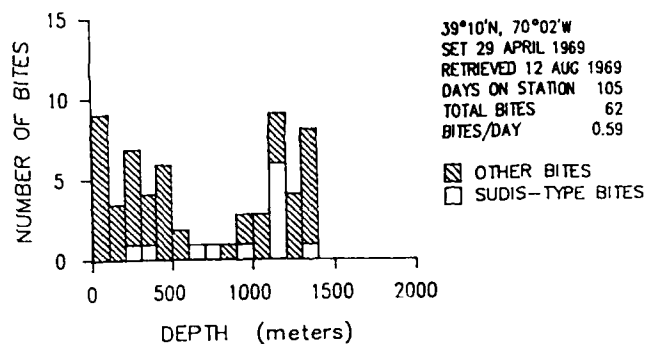


Figure 10. Number of bites vs. depth (Stations #298 and #300).

The total number of cuts in these moorings was 115, much less than in the previous (Bermuda) case. In terms of bites per day of exposure, a less concerted attack was noted. In addition, most of the bites were closer to the surface. A different species of biter seems indicated. The frequency of fishbite occurrence as a function of depth for all moorings set in the Fishbite Zone over the period considered in the report is presented in Figure 11.

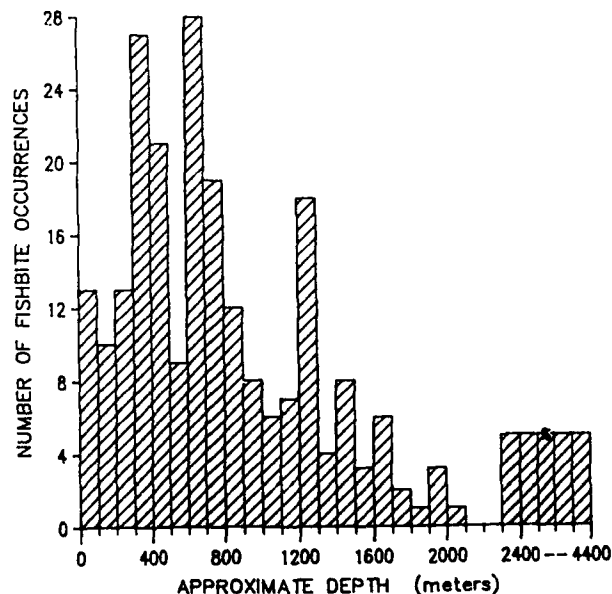


Figure 11. Number of fishbites vs. depth (Worldwide).

The data shows that 91% of the bites occurred at depths shallower than 1500 meters and 97% at depths shallower than 2000 meters. Moreover, it may well be that the few bites recorded as great depth bites in fact occurred during launch or recovery. The great majority of fishbite incidence was between the surface and 1000 meters depth.

#### B. The National Data Buoy Center (NDBC) experience.

The NDBC conducts research, development, testing and deployment of buoys and moorings in the deep ocean environment. The center was established by the Coast Guard in 1967 and transferred to the National Oceanic and Atmospheric Administration (NOAA) in 1970. Since this time, NDBC has continued to operate a moored buoy fleet for providing real-time meteorological data to the National Weather Service.

Between the years 1972-1980, NDBC utilized predominately large buoy hulls (10 meter and 12 meter discus) and large mooring lines. Typically, these were 2 inch diameter or larger synthetic fiber ropes. During this period the buoys were located mostly along the continental shelf and the network numbered only between 10 and 25 buoy stations. Only 1 confirmed fishbite failure occurred, in the Gulf of Mexico on a 1 3/4 inch diameter mooring line that had been in use for 243 days. Two other mooring line failures occurred during this time period which appeared to be fishbite related, but could not be confirmed.

During the early 1980's the NDBC's buoy network expanded considerably to more than 40 buoys with many buoys in depths greater than 10,000 feet. Smaller NOMAD buoy hulls were primarily used in deep water locations. The NOMAD is an aluminum boat hull buoy, 20 ft. long by 10 ft. wide with approximately 1/5th the deployment weight of a 10 meter discus hull and nearly 1/10th that of the larger 12 meter discus buoy.

This smaller hull resulted in reduced mooring loads and thus, enabled smaller mooring lines to be used. With an expanding buoy network, the smaller mooring cables also resulted in lower costs for deep ocean moorings. It was during this period that the number of fishbite failures began to increase. From 1980 to 1986, 11 mooring line failures occurred that were attributed to fishbite. Table 1 is a summary of these failures in the years in which they occurred.

Most failures were reported in the Gulf of Mexico or Southern Atlantic Ocean. One failure occurred at a Hawaiian station. All stations were in the Fishbite Zone.

Of the lines that failed, all were less than 2 inch in diameter. Analysis of the failures almost invariably showed that the failure resulted in a cut through only 50-75% of the rope fibers with the remaining fibers failing in tension. This would indicate that once the line was bitten, it continued to operate until such time the mooring load exceeded the strength of the remaining fibers.

Table 1

#### NDBC FISHBITE MOORING FAILURES

	LOCATION	SITE DEPTH (FT)	DAYS ON STATION	TYPE MOORING LINE	FAILURE DEPTH BELOW SURF (FT)
1980 3 FAILURES	25-54.3 N 89-42.4 W	11,040	71	1.75" DIA NYLON	545
	25-00.0 N 88-00.0 W	10,600	1,118	1.25" DIA NYLON	3,350
	26-00.0 N 93-30.0 W	9,996	724	1.625" DIA NYLON	1,350
1981	NONE				
1982 1 FAILURE	34-54.2 N 72-53.5 W	13,860	377	1.75" DIA NYLON	820
1983 2 FAILURES	29-18.0 N 77-18.1 W	3,210	293	1.125" DIA NYLON	350
	23-24.0 N 162-18.0 W	10,680	886	1.75" DIA NYLON	2,075
1984	NONE				
1985 3 FAILURES	29-18.8 N 77-19.8 W	3,270	868	1.125" DIA NYLON	220
	32-18.0 N 75-17.4 W	12,396	1,190	1.75" DIA NYLON	1,500
	25-54.9 N 89-42.7 W	10,200	909	1.75" DIA NYLON	950
1986 2 FAILURES	32-16.0 N 75-14.0 W	12,000	46	1.125" DIA NYLON	1,400
	29-19.0 N 77-21.0 W	3,420	377	1.125" DIA NYLON	2,800

AVERAGE DEPTH OF FAILURE — 1,393 FEET BELOW SURFACE

AVERAGE TIME ON STATION — 623 DAYS

This would lead to the conclusion that an oversized mooring line may be able to withstand a fishbite attack yet, retain enough strength to keep a buoy moored on station. Although an oversized mooring line involves additional initial cost, it may provide increased reliability of the overall mooring system for long term use.

This rationale was used on two mooring systems deployed by NDBC off the coast of South America in 1985. Located within the fishbite zone and nearly 1500 miles off the South American coast, it was felt that a larger diameter mooring line may help insure a long term mooring. Two 3 meter discus buoys were deployed using 1 3/4" diameter nylon and 2 1/4" diameter polypropylene mooring line in late 1985. The moorings are still in use today.

Two other failures occurred while the buoy was being serviced in 1985 and 1986. In each case the buoy had been placed on deck for electronics and sensor servicing when it was noted that the mooring had parted. On recovery of the nylon mooring line, recent fishbite was found to be the cause. Servicing usually requires several hours with the attending ship attached to the mooring. The ship's movement (due to wind, current and maneuvering) keeps the mooring line in constant motion, much more so than when the small buoy is attached. Similar fishbite attacks have been experienced by the U.S. NAVY of acoustic arrays towed by surface ships.

#### C. Experience Worldwide.

When the information on all sources which have reported fishbite attacks to WHOI is plotted on a world chart, the geographic distribution of fishbite incidence is as shown in Figure 12. This chart seems to corroborate the relation between fishbite and warm surface water. However, it must be noted that more data should be acquired to properly represent all of the world oceans.

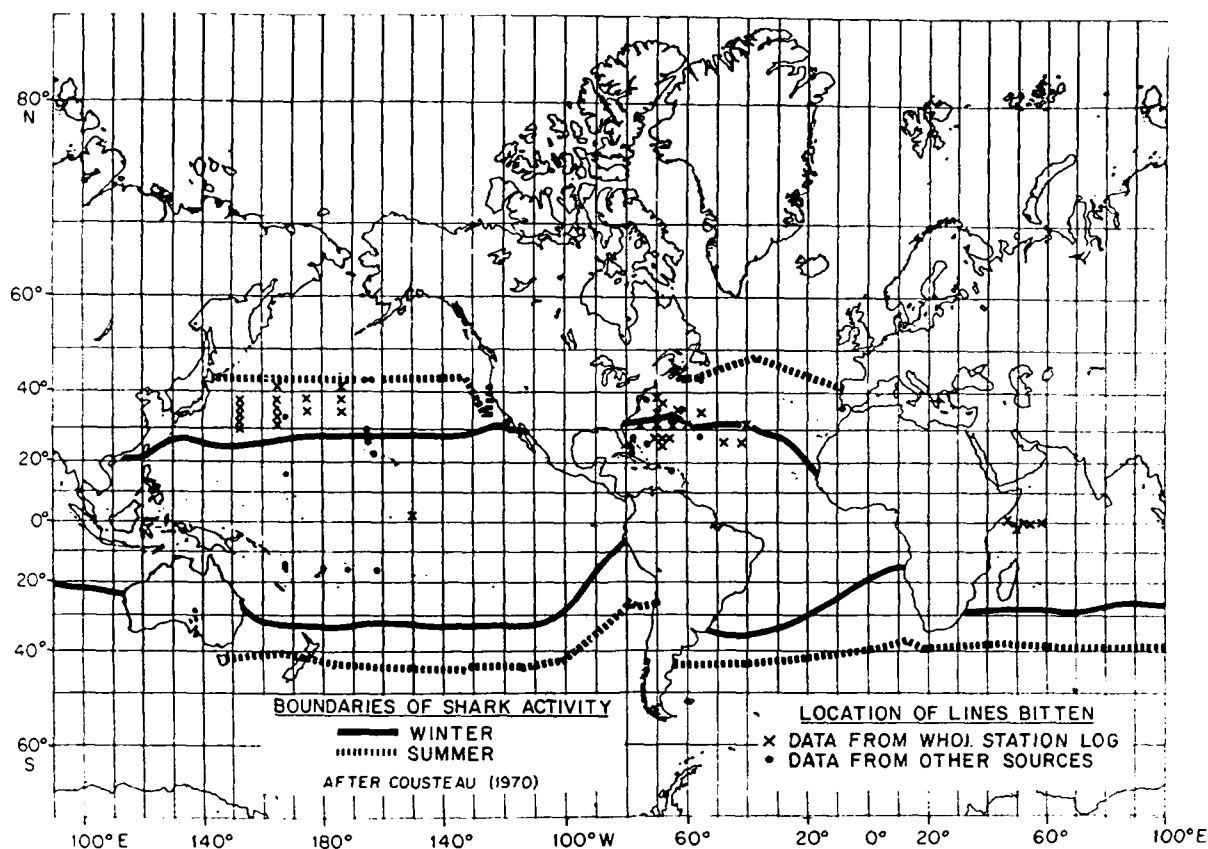


Figure 12. World geographic distribution of fishbite incidence.

#### BITING ORGANISMS AND PREDISPOSING FACTORS

An excellent description of the pelagic environment in which deep sea moored structures must survive is given by Isaacs (14). Essentially two populations of predators have been identified as responsible for most of the recorded fishbites: those who spent most of their time at or near the surface (epipelagic zone) and those who strive in the lower half or near the bottom of the thermocline (mesopelagic zone). Inhabitants of the mid and deep waters do not constitute an appreciable threat nor do bottom dwellers. Yet large predators (grenadiers and sharks) have been photographed close to the bottom in very deep waters (7 & 15).

It has been known for a long time that marine life becomes centered around lines moored at sea. A considerable variety of organisms may be found. Some are sedentary, such as barnacles, bryozoa, and algae fastened to items in the array. Others are pelagic and include squid, small and large fish and visiting porpoises. Considering possible biters in order of their phylogeny, the first candidates are found among the Mollusca. Squid and perhaps octopus would seem to have biting capabilities worthy of consideration. There are few records which indicate that squid have been closely associated with mooring lines. Marra (17) found squid parts including beaks inside the stranding of synthetic fiber ropes. Turner (28) reports a squid bite on a cable placed in the Arabian Sea. It

seems doubtful that squid can produce the clean cuts seen in synthetic fiber mooring lines.

Fish, on the other hand, have been repeatedly implicated in attacks upon mooring lines and instruments. Sharks have been frequently encountered and captured in the vicinity of buoy sites. Species which have been positively identified by capture, or by the imprint of their jaws or the teeth left imbedded in mooring components include: silky (1), mako (24), white tip and great blue (23). Figures 13 and 14 which picture the jaws and the teeth of two carcharhinid sharks illustrate the formidable cutting capability that sharks possess.

At least three mesopelagic fishes have been implicated in damage to deep sea moorings. The first identified deep sea biter was *Sudis hyalina* (12). It is a fish with strongly developed teeth in the lower jaw only (Figure 15). The teeth have serrated edges, are very sharp, and are efficient stabbing tools. The average length of the fish is 40.5 cms.



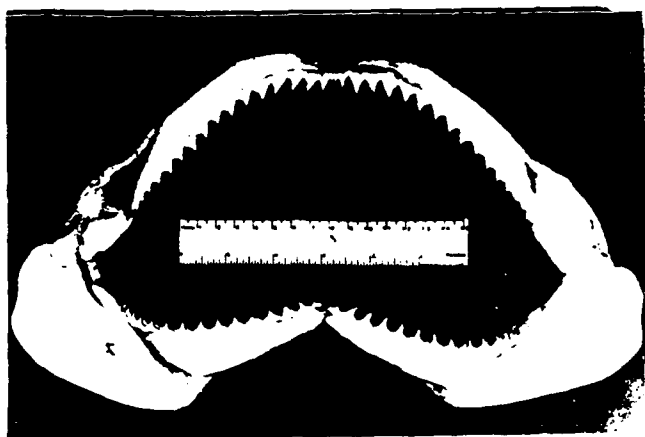


Figure 13. Jaw of Carcharhinus falsiformis (silky shark).



Figure 14. Teeth of Carcharhinus longimanus (white tip shark).



Figure 15. Sudis hyalina.

A second bony fish which produces bites at considerable depth was found off the west coast of Spain, as described by LeGall (16).

Positive identification of the biter was again established from tooth fragments and habitat. It proved to be "sabre" or "espada", a well known food fish (scientific name Aphanopus carbo) which is captured commercially by long lining at depths of 500 to 1000 meters (Figure 16). Its average length is 100 cms.

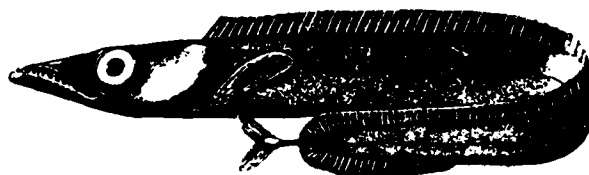


Figure 16. Aphanopus carbo.

Finally the lancet fish (Alepisaurus ferox, Figure 17), with an average length of 100 cms, was also positively identified as a deep sea line biter. Many other potential biters of the mesopelagic zone are described in references (6), (18), and (20).

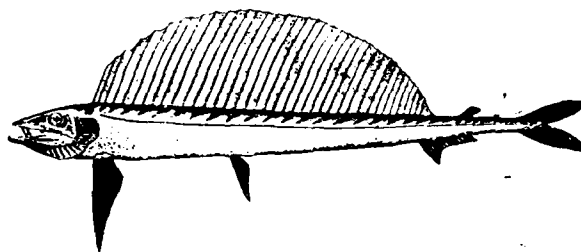


Figure 17. Alepisaurus ferox (lancet fish).

It is known that sharks and bony fish have in varying degree, capabilities for detecting and responding to sound, pressure gradients, light, odor, taste, mechanical touch, temperature, electric fields, and magnetic fields.

At first thought, a small, black, inert plastic line may seem to be a sorry bait, but consider its history as part of a moored array. Before the line even gets into the water, the interest of marine organisms has been aroused on a massive scale. A 1000 ton ship ploughs its way to the mooring site expending energy in stirring up the water at the rate of 2000 hp. It is a mixture of steady tones, swishes, splashes, and thumps. Tastes and odors are strewn along the way as fouling on the ship's bottom is washed. If garbage is thrown overboard it adds to the chumming. By the time the mooring site has been reached, signals of sight, sound, and pressure fluctuation have heralded some unusual event and a trail of chemical clues may have been established for miles. If there are phosphorescent organisms in the area, the ship's wake may be lighted as well. At night, working lights are an attraction to squid and small fish which in turn excite the interest of biting predators.

During deployment of a mooring, there are some additional attractions. If it is a buoy first mooring, there will be irregular noises as the buoy goes overboard, then a period when line and instruments are paid out. To keep the array from tangling, the ship will be moving slowly, at perhaps 3 knots. Biting fish which have been alerted may find targets at this time, especially if there are bright and/or light colored items in the line. After deployment and while the moored

array is on station, algae, goose barnacles, hydroids, and bryozoa grow on parts in the photic zone, down to 100 meters or more. Below, in the dark, gelatinous organisms, such as siphonophores, often become entangled on the line. If they are or become phosphorescent the line will be lighted. If the line strums in a current, it may announce its presence.

When the line is hauled, conditions are similar to those at the time of setting with two added features. One is the presence of organisms on the line which add to the baiting process as they are dragged through the water. The other is the disturbance of a community of fish and other organisms which was an orderly establishment while the line was moored, but which now becomes a scramble of baits.

From the foregoing account, it must be evident that the process of operating a deep sea moored station gives rise to a lot of stimuli over an area that can be miles long and many meters wide. How effectively these different signals are in attracting line biters is further reviewed by Berteaux and Prindle (5).

#### DETECTION AND IDENTIFICATION OF FISHBITE DAMAGE

Granted that fishbite is a cause of damage to deep sea lines, how does one go about distinguishing it from other types of damage when confronted with an item which has failed or was damaged in service? In a few cases, biting has been observed while in progress, or teeth may be found embedded in an area of damage. Most of the time however, it is necessary to arrive at a conclusion by assembling bits of evidence long after the event.

If possible, the first observations should be made as the mooring line is being hauled from the water. The observer should look for cuts, gouges, and scrapes in the plastic jacket or for sharply cut yarns which stick out of the rope surface. When found, a brief description of the damage should be recorded. In addition the whole line or at least the damaged portion should be saved for later study in the laboratory.

In the laboratory, a line suspected of having been bitten should first be examined as received. If by good fortune, the whole shot of line is available, it should be examined foot by foot for indications of fishbite and other biological activity such as fouling. Such a procedure is at times tedious, but experience has shown that it usually leads to discovery of more biting damage than is seen at sea where the main concern must be hauling the line on schedule. It is during this close examination that teeth and tooth fragments are most likely to be found. After detailed examination, the line sample should be rinsed in fresh water and dried for microscopic examination.

Plastic covered lines usually retain dental impressions when bitten. Organized patterns of tooth spacing or teeth marks may be found.

Fishbites are characterized by being clean, sharp cuts which often cannot be duplicated by cutting with the blade of an ordinary pocket knife or even a new razor blade.

Finding teeth or tooth fragments in a plastic jacket is of course the ultimate confirmation that fishbite has occurred. Occasionally, whole teeth may be found, but more often there are only fragments identified as bits of tooth. As evidenced in Figure 18, the use of X-ray can help confirm the presence of embedded teeth.

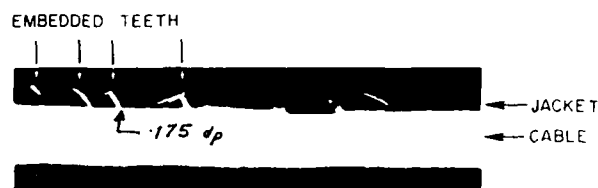


Figure 18. An X-ray of a polyethylene jacketed line revealing shark teeth in situ.

In summary, recognition of fishbite in a plastic jacketed rope results from observations of tooth fragments, dental impressions, pattern of cuts, and sharpness of cuts.

Fishbites inunjacketed fiber lines may show up as sharply cut yarns or strands which often stick out from the side of a rope. If the line has parted in service, and only a fag end is retrieved, it will often be found that many of the yarns have truncated ends, which indicates cutting by a sharp instrument, such as fish teeth. At the same time, the ends of a few yarns may have a 'ponytail' appearance, which is indicative of tensile failure. Such a pattern is characteristic of a line which had most of its yarns cut by fishbites, leaving only a few yarns to sustain the tensile load (Figure 19).

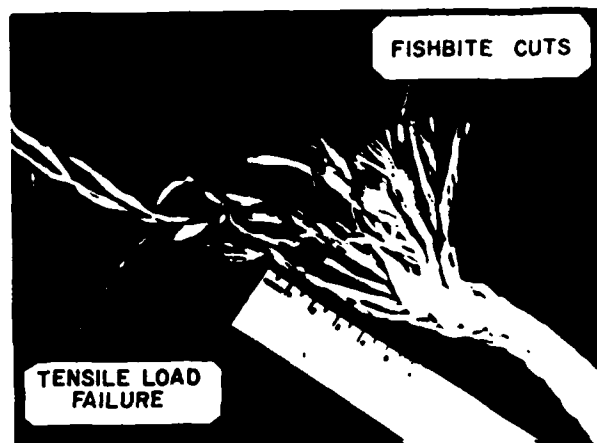


Figure 19. Synthetic fiber rope typical fishbite failure.

A reasonable assessment of the modes and causes of a rope failure almost invariably requires a formal investigation conducted in the laboratory. The fag

end of a line which reaches the laboratory is often a hopeless looking, amorphous mess of dirty fiber. Yet, a record of the cause of fiber failure usually remains in the morphology of the fiber ends. It can be read under the microscope as demonstrated by the work of Hartman (13).

The steps followed in the laboratory analysis of failed ropes include:

- Preparation of representative samples for macroscopic and microscopic examination.
- Distribution of failed fiber ends into representative categories.
- Comparison of the data set obtained against standards.
- Interpretation and report.

These steps are presented in detail, together with an extensive collection of macroscopic and microscopic signatures of parted fiber ends in Berteaux and Prindle (5). These comparison standards reproduce the causes and modes of damage most likely to be encountered in mooring line service (cutting, tension, abrasion, etc...) and encompass rope materials commonly in use (Dacron, Nylon, Polypropylene and Kevlar). An example of these signatures is shown in Figure 20.

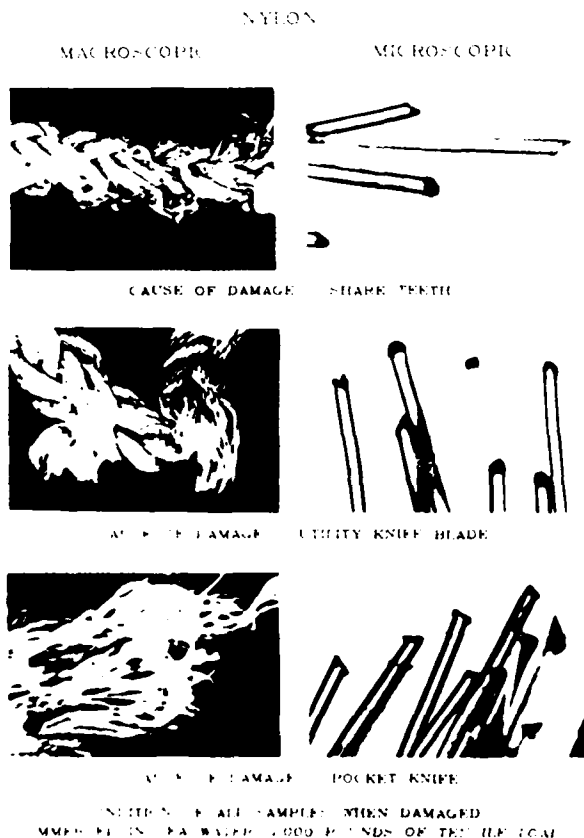


Figure 20.

To ascertain if fishbite was the most probable cause of the line failure, the best approach is to first isolate the mode of failure, that is the

manner in which the mechanical damage was inflicted. If no cutting is evident then fishbite a priori should not be considered as causative. On the other hand, any positive indication of cutting should prompt further investigation to identify the instrument, including fish teeth, which destroyed the line integrity.

Ropes which have been cut characteristically have yarns with truncated, even, square ends. The cut yarns are usually found at the same location along the rope. Fiber ends in a cut rope are predominantly Sharp cut and/or Shear cut. Cuts which have been made by a keen edge will contain mostly Sharp cut fiber ends. As progressively duller and more uneven edges are encountered, the percentage of Shear cut ends increases, and some Torn fiber ends may be produced. Kevlar fibers also develop Split ends.

If it has been determined that cutting by a very sharp edge caused the failure of the mooring line, then the possibility of fishbite should be considered next. If teeth or tooth fragments are found in the damaged area then the cause of failure most probably is fishbite. Most of the time no teeth are to be found. On the other hand, a rope damaged by fishbites will show characteristic patterns such as: paired cuts a few centimeters apart, caused by teeth on opposite sides of a jaw; cuts separated only by one or two centimeters due to adjacent teeth on one side of a jaw; cuts on both sides of the rope due to upper and lower jaw teeth; or other cuts, meters away from the severed end, indicative of additional bites. In short, if the cuts are very sharp and their spacing commensurate with known tooth arrangements and jaw dimensions, then the probability of fishbite is very good.

The case of the "single" cut is more difficult to resolve. If the "single" cut is clean across the rope then the probability of cuts other than fishbite exists. Perhaps the rope was deliberately cut, perhaps it was accidentally cut over a sharp edge, a broken glass float for example. Documentary evidence, records, depth at which cut was made would greatly help confirm the suspicion. Without this however, it may be impossible to differentiate between natural (fish attack) and artificial (man made) cause of failure.

If the "single" cut is a partial cut followed by a tensile break then chances are good that the line was damaged while in service, most likely while on station. In this case, fishbite becomes the prime suspect again. This fishbite identification process is schematically depicted in Figure 21.

If the cut end appearances reveal that the cut is most likely not fishbite, then other causes of damage must be investigated using the standards of comparison previously described and/or any available circumstantial evidence.

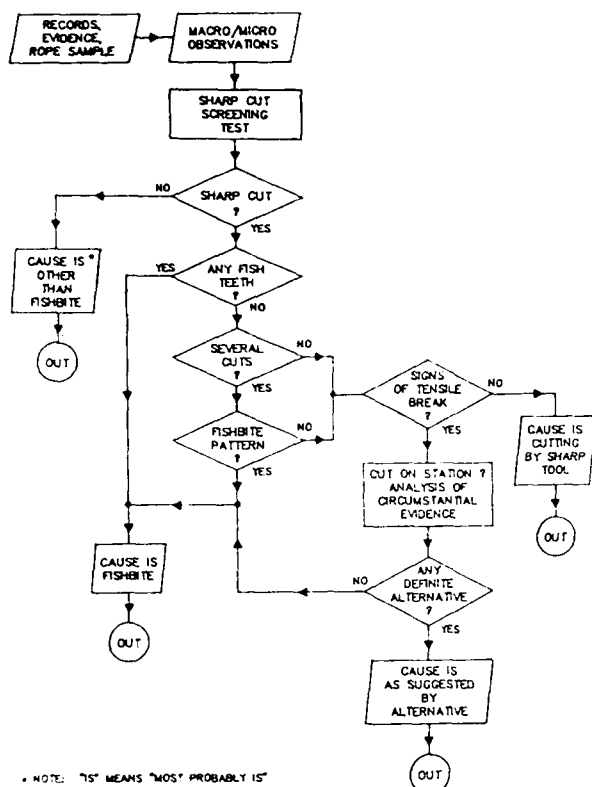


Figure 21. Fishbite identification flowchart.

#### PREVENTION AND CONTROL OF FISHBITE DAMAGE

Prevention measures include selecting sites outside of the "danger zone," reducing the attractiveness or incentive mechanisms, and the use of repellents whenever practical. Common sense would dictate to stay out of the Fishbite Zone whenever possible. This approach, of course, is very restrictive. The experience of fishermen who try to encourage fishbiting by the use of flashy lures should be applied in reverse. Eliminating the metallic shine of mooring components such as cable connectors by taping or spray painting should be helpful. Obviously mooring lines and their inserted instruments should have dull, unattractive colors with minimum contrast against the environment. Greenish grey, light blue, and black are indicated.

The low frequency vibration of small, taut mooring lines induced by currents can be attractive to fish. Mooring line strumming can be effectively reduced or entirely suppressed by inserting tear drop shaped fairings. Ropes equipped with plastic ribbons or protruding "hairs" will also be free of flow induced vibration.

As time passes, mooring lines and their instrumentation deployed in the photic zone will accumulate layers of marine growth and become fouled by marine organisms. This fouling process results in a sustained food chain that rapidly develops at the mooring site, thus increasing the possibility of fish attacks. Antifouling treatment

of buoy hull and all mooring components down to at least 100 meters is the obvious remedy to the problem.

The fascinating behavior of sharks has been extensively studied and various means for repelling sharks or deterring them from attacking have been investigated and reported (23). These means include chemical repellents, acoustical and electrical fields and physical barriers. All these techniques require chemical supplies and power resources which cannot be stored or provided by standard, state of the art mooring technology.

At present, practical methods for control of fishbite by repelling deep sea biting organisms are not available. Therefore, when lines are to be exposed to the ocean environment within the Fishbite Zone, they must have sufficient structural resistance to biting attack to survive their expected service life.

Curative methods, that is these techniques which hopefully immunize and protect mooring lines from failure due to fishbites, include the use of metallic ropes, the use of large diameter non-metallic ropes, and barriers of metal or hard plastic placed over non-metallic ropes. Long term surface and subsurface moorings routinely use wire ropes from the surface down to a depth of 2000 meters. Jackets of plastic materials (polyurethane, polyethylene, polyester, etc.) are often extruded over wire ropes. These jackets provide a water barrier which greatly reduce the corrosion fatigue of wire rope and substantially increase their useful service life (19).

Early experience with synthetic fiber mooring lines of large diameter (one inch or more) seemed to indicate that these larger ropes were less susceptible to failure from fishbites than the smaller ones. However, as more and more ropes were sent to the laboratory for analysis, it became evident that large rope often had many bitten yarns. Some even had failed entirely due to repeated biting. The greater survival rates of larger ropes result simply from their bulk. A few cuts cannot diminish the rope strength to the point where it would fail in tension. Size does not deter biting but it certainly helps in keeping the mooring's integrity.

To be useful within the Fishbite Zone, synthetic fiber ropes must be protected against fishbite. Certainly no material exists today which can protect a fiber rope from the furious bites of a large shark in the throws of a feeding frenzy. Fortunately pelagic sharks spend most of their time near the surface with occasional deep sea dives. What is required is a jacket material or armor which can reasonably protect the ropes in the majority or cases: inquisitive bites, nibbling, and the constant attack of the smaller and deeper benthic species. If the use of metallic mooring lines could be limited to the first few hundred meters of the water column, the weight saving would incite and permit the development of novel mooring applications. Over the years the authors have

developed test procedures and standards to assess the resistance to puncture and cutting of candidate jacket materials and braids. As a result of this work reasonable numbers emerged to quantify the penetration and cutting resistance requirements for "good" jacket and armor materials. The puncture force required for a sharp pointed tooth to penetrate 1/8th of an inch of jacketing material should be larger than 75 lbs. Similarly the cutting force to completely sever a 1/4 inch diameter armored rope should be larger than 40 lbs. These numbers express a compromise between polyethylene which has been widely used but will not give enough protection under severe attack and some other materials which are tougher but tend to be unmanageable. Polycarbonate is an example of the latter. In addition to being difficult to cut, "good" armors should be easy to extrude over the ropes to be protected. They should not impair the usefulness and ease of handling of the original rope by undue stiffness, and they should resist the environmental conditions usually encountered in mooring line service.

A set of requirements based on our present experiment and research of the field for candidate jacket materials is outlined in the data sheet shown in Table 2. This specification's primary purpose is to aid in the screening process of plausible plastics. The limits indicated in this fishbite armor specification represent what is thought to be reasonably ideal for armoring lines with diameters between 0.24 and 0.50 inch. Changes in size, particularly with larger diameter ropes, may yield somewhat different values. The properties listed are grouped into several categories. The first group relating to cut and stab forces is critical. Materials which fall below the indicated limits are not likely to make effective armors.

The second group of test under "Toughness" includes factors which bear on the capability of a material to absorb abuse and remain serviceable. In general, the higher the values the tougher the material. If tensile modulus is too high the armor will carry too much tensile stress as the line is loaded. Excessively high flexural modulus will make the line too stiff to handle. On the other hand, elongation should be sufficient so that the armor is not broken when the line is extended under load. In terms of overall utility, specific gravity is not a limiting factor for most thermoplastics. Under "Thermal properties" melting and extrusion temperature limits are related to the thermal tolerance of the tensile fibers used particularly with reference to extrusion. "Brittleness temperature" and "Use range" govern the handleability of an armored line. A practical range of temperature requirements should span from a low of  $-40^{\circ}\text{C}$  to a high of  $50^{\circ}\text{C}$ .

Environmental resistance is necessary if a line is to be used repeatedly. Resistance to stress cracking is essential. Hydrolysis and other effects due to water are significant in a material

Table 2

PROPERTIES:	TEST	UNITS	DESIREABLE LIMITS	CANDIDATE ARMOR
<b>CUT RESISTANCE</b>				
FORCE TO CUT	DSLFM *	lbs	38 min	
FORCE TO STAB: STEEL TOOTH	DSLFM *	lbs.	75 min	
DURUMETER	ASTM 2240	Shore D	75 min	
<b>TOUGHNESS</b>				
IMPACT, NOTCHED IZOD	ACTM D256	(ft)lb/in	5 min	
TENSILE MODULUS	ASTM D638	$(10^3)\text{lb/in}^2$	10 max	
ELONGATION TO YIELD	ASTM D638	%	10 min	
ELONGATION TO BREAK	ASTM D638	%	20 min	
FLEXURAL MODULUS	ASTM D790	$(10^3)\text{lb/in}^2$	4 max	
<b>SPECIFIC GRAVITY</b>				
			1.50 max	
<b>THERMAL PROPERTIES</b>				
MELTING POINT		$^{\circ}\text{F}$	**Varies	
EXTRUSION TEMPERATURE		$^{\circ}\text{F}$	**Varies	
BRITTLINESS TEMPERATURE	ASTM D746	$^{\circ}\text{F}$	0 max	
USE RANGE		$^{\circ}\text{C}$	-40 to 120	
<b>ENVIRONMENTAL STABILITY</b>				
STRESS CRACKING			Excellent	
HYDROLYSIS			Excellent	
ULTRA-VIOLET RADIATION*			Excellent	
<b>RATING</b>				
* DSLFM = Deep-Sea Lines Fishbite Manual (Prindle & Walden, p.62, 1975) ** Related to thermal properties of other line constituents.				

which is to be used for long periods under water at considerable pressure. Resistance to sunlight and oxidation are important. In general, carbon black has been successful as an ultra-violet light screen. It also has the added advantage of lowering the visibility of lines used under water.

Candidate jacketing materials which exhibit good potential as rope armors and deserve consideration for further evaluation at sea are the following Thermoplastics: ABS (Uni-Royal, Kralastic SR-S-1801), Fluorocarbon (duPont de Nemours, Tefzel 280; Allied Chemical, Halar 300), Nylon 6 (Allied Chemical, Capron 8220), Nylon 6/6 (duPont de Nemours, Zytel ST801), Polyester (duPont de Nemours, Hytrel 7246), PVC compound (Firestone, FPC 1442-143; Goodrich, Geon 8700A). Other compounds which have favorable properties but which have yet to be screen tested are: ABS alloys (Commercial Plastics, ABS polycarbonate alloy; Borg-Warner, Cyclolac), Isocyanated based resins (Upjohn, Isoplast), Nylon 6/6 (duPont de Nemours, Zytel ST900), Nylon 11 & 12 (Rilsan Corp., Rilsan), Polycarbonate modified (General Electric, Xenoy & Elastomer modified; Mobay, polyester modified), Polyphenylene oxide modified (General Electric, Noryl), Polyvinyl chloride (PVC) modified (Occidental Chemical, Oxytuf, graft co-pol. with vinyl, & EPDM; Goodrich, Geon).

The thermoplastic industry is very dynamic and new materials appear in the market every year. Some may exhibit characteristics superior to those of the promising materials above mentioned. Readers

interested in this fast evolving field should remain alert and cognizant of the new products and techniques as they become available.

New metallic and synthetic fiber braids of Kevlar and Spectra have been recently tested, some of them quite successfully. Table 3 is a summary of these results.

Table 3

Results of laboratory tests on "bite" resistance of some lines armored with braided covers

NO.	CONSTRUCTION		STAB FORCE (lbs)		CUT FORCE (lbs)	
	CORE DIA. FIBER	JACKET (mils)	NO TENSION	1125 lbs TENSION	NO TENSION	1125 lbs TENSION
1	5/16" Kevlar	Polyolefin (35) Aluminum braid Polyolefin (41)	27	38	306	264
2	3/8" Kevlar	very fine Kevlar braid	13	50	377	> 480
3	1/4" Spectrum 900	Urethane Metal braid	35	58	221	300
AC	13/32" Polyester	Acetal Copolymer (78)	63	38	121	> 45
N	13/32" Polyester	Nylon 6/6 (63)	39	31	104	> 37

Good fishbite resistance  
marginal

The data presented in Table 3 indicate very high resistance to cutting by all three of the braid covered lines. On the other hand, resistance to stabbing is better in a line armored with a tough plastic like acetal copolymer (item AC), but it drops when stressed. The stab resistance of braid covered lines increased substantially when tension was applied. It will be interesting to see what happens when these lines are tested at sea.

#### CONCLUSIONS

Analysis of the data from 550 WHOI moored stations, established in the years 1967 through 1985, leads to the following conclusions: 1) 99.3% of fishbites occurred within an ocean space designated as the Fishbite Zone which was bounded by 40° North and South parallels and depth levels of 0 and 2000 meters. 2) Fishbite is a significant hazard to deep sea mooring lines. It was reported to occur on 27% of all lines set within the Fishbite Zone. 3) Risk of fishbite was found to be inversely correlated with latitude from zero at approximately 42° North to 63% of the lines set within 5 degrees from the equator. 4) Within the Fishbite Zone, moorings with buoys between the surface and 1000 meters depths are most susceptible to fishbite attacks. Below 1000 meters fishbite hazard falls off and is 0 at 2000 meters depth and deeper. 5) The data base shows a definite trend of increase of risk as exposure time increases. It is reasonable to expect that on an average, one mooring out of four will be attacked if set within the Fishbite Zone for a period of up to 450 days. Fishbites are relatively easy to locate and identify in plastic covered metallic and non-metallic cables and ropes. The traces or markings left by the teeth and sometimes the teeth or tooth fragments embedded in the jacket have been used to

identify the aggressors and characterize the patterns of damage.

Fishbite damage in unprotected fiber ropes is more difficult to positively identify. A screening test must confirm that a sufficient percentage of the fibers have been "clean" cut. When this is the case the possibility of fishbites must be further confirmed by presence of teeth, or patterns of cuts, or direct evidence, or by elimination of other possible alternatives.

Fishbite identification still remains a patient art. Statistical evaluation of microscopic observations done on well prepared specimen is an essential tool for a rational interpretation of failure causes.

NDBC's primary mooring goal remains to deploy lightweight, long term (6 years life minimum) deep water mooring systems. The recent increase in fishbite failures over the past few years has prompted NDBC to pursue an active research plan to study the fishbite phenomenon and its countermeasures.

WHOI, under the sponsorship of the Office of Naval Research and NDBC will continue to serve as a central collector of fishbite data. Research in fishbite protective armors will be pursued. Actual field test of the best protective armors and braids is anticipated to take place in the North Atlantic in 1988.

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